UNDER COVER

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The impermeable properties of flexible membrane liners have made them hot properties for landfill closure-cover systems. But slip-resistant clay might still be the best cover material in areas where seismic stability is a major concern.

For years, flexible membrane liners (FMLs) have proven to be successful components of landfill liner systems—so successful, in fact, that researchers and regulatory agencies are recommending FMLs more often for inclusion in closure-cover systems. They rightly argue that the impermeability of FMLs makes them desirable candidates for closure covers (CE May 1992). What they fail to consider sufficiently is the issue of stability. If designers insist on installing FMLs as part of landfill cover systems, infiltration-potential and seismic-stability analyses must be performed before proceeding with installation of the final cover.

Landfill liners typically do not experience stability problems, because the normal forces exerted by the completed landfill offset sliding resistance along the sides of the landfill liner system. In contrast, closure covers, particularly those constructed on steep slopes in areas of high seismicity, are inherently vulnerable to movement. Add the low frictional resistance of the materials used in the construction of FMLs to the mix, and the likelihood of failure at the interfaces between these materials and other cover components increases.

To get a clearer picture of the inadequacy of FMLs as barrier layers in cover systems, consider the case of polyethylene. One of many synthetics recommended for use as an FML in multilayer closure covers, polyethylene is familiar to many as the material that covers the bottoms of their skis. It provides not only an impervious layer between the ski and the snow but also low-frictional resistance, its primary characteristic, which helps the skier slip over the snow. Whereas the skier seeks to eliminate stability, the designer of a waste-disposal closure cover must strive to achieve it.

SYNTHETIC VS. CLAY

Regulatory agencies and others have tended to overlook the stability issue regarding closure covers. They believe that only impermeable materials such as FMLs can provide a barrier sufficient to keep waste materials from migrating into surrounding areas or rainwater from infiltrating the landfill mass. A compacted clay layer, however, if carefully designed, constructed and maintained, may provide a better combination of stability and impermeability.

The stability of a landfill cover system may be jeopardized by deep-seated failure or by veneer failure of the cover-system layer components (either static or seismic). Veneer failure depends on the material properties of the cover system and the landfill slope. The principal factors that govern whether a cover system is susceptible to veneer failure are the geometry of the embankment, the friction angle between the interfaces of different synthetic materials or the synthetics and the soils, and the water level above the FML.

Four interfaces in a typical Resource Conservation and Recovery Act (RCRA) closure cover with an FML (cover system A) are candidates for veneer failure: soil to filter cloth, filter cloth to drainage net, drainage net to FML and FML to clay layer (see figure). For the purpose of this article, I examined the stability of these interfaces for slopes ranging from 2:1 to 3:1 using the STABLE2 computer program developed by Purdue University. Stability analyses for each of the four failure modes were performed twice, once for high-water-table conditions and once for low-water-table conditions. For the high-water condition, the water table was assumed to be parallel to the drainage net. For the low-water condition, the water table was assumed to coincide with the drainage net at the top of the slope, but lie 0.3 m (1 ft) above the drainage net at the bottom of the slope (the bench). Between these two points, the water table was assumed to vary linearly. The first condition is likely to occur most of the time, and the second condition occurs only if the drainage system becomes blocked at the bench drain or landfill toe.

The stability of a slope having a safety factor of 1.5 or higher is considered to be acceptable for long-term (static) design for all types of embankments (such as reservoir dams and solid-waste-disposal structures) and cuts or natural soils. A minimum friction angle of 19.7 deg. between any two synthetic components (or between any synthetic and soil) is required to achieve the desired degree of stability. A review of available literature indicates that the friction angles between FMLs and geotextiles range from 8.4 to 11.8 deg.; between FMLs and compacted clay, from 7 to 14 deg.; and between FMLs and geonets, from 7.3 to 10 deg. With these friction angles, a safety factor of 1.5 cannot be achieved under static loading conditions for any analyzed slope. Conditions become even worse under seismic loading. Slip failure along synthetic interfaces becomes almost inevitable under seismic loading for any slope steeper than 3.5 horizontal to 1 vertical.

Because FMLs are inherently unsuitable for use on steep slopes, engineers must find

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ways to incorporate them into the overall cover system. One method is to break the FML into smaller pieces and "nail" each piece into the slope while the pieces are simultaneously overlapped, like roof tiles. This would not jeopardize infiltration potential, and would greatly increase stability and simplify installation and repair work. But this method would not work when the FML also has to function as a gas collector, which happens often with municipal-waste landfills.

LONG-TERM MIGRATION

Both federal and state regulations require that long-term migration of liquids through the cover and into underlying wastes be minimized. California's regulations are somewhat more explicit, citing a period of at least 100 years.

These regulatory requirements can often be met without a drainage layer or an FML, as shown by a detailed analysis of the expected runoff and infiltration rates on landfill slopes where the grade exceeds 10% (10 horizontal to 1 vertical).

The difference between flat and pitched roof decks offers an even clearer example of this analysis. Generally, flat roof decks are covered with materials like asphalt, coal tar or foam. These materials are virtually waterproof and must be installed as a single unit without leaky seams or cracks. This barrier is necessary because water has a tendency to collect and pond on flat roofs before it flows slowly to drainage outlets or evaporates. In contrast, water flows more swiftly down steep roof decks and never has the chance to collect in depressions. Such roofs are typically constructed of multiple units (like shingles or tiles) that are sometimes, but need not be, impermeable.

Any rainfall that contacts a landfill cover will become runoff or evaporate from depressions on the surface or infiltrate into the vegetated layer. Of the fraction that enters the soil, a portion will remain in storage in the soil pores or be lost to the atmosphere due to evaporation and transpiration; the rest will eventually migrate downward. If a cover system is to function properly, little if any water that falls on it should migrate beyond the compacted-clay-barrier layer and into the waste.

A QUESTION OF SLOPE

Cover system B has neither an FML nor a drainage layer. Two features of this cover system—the slope on which it is installed and the 1 m thick layer of compacted clay—combine to minimize the amount of water that is likely to come into contact with the wastes beneath it.

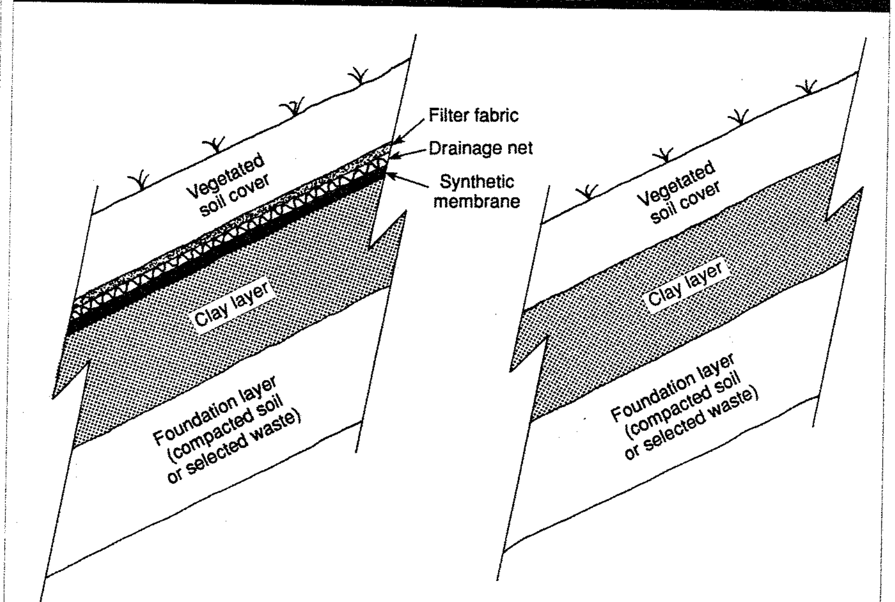
The steepness of the cover provides the initial barrier to infiltration by promoting greater runoff during rainfall events. Data in the Solano County, Calif. *Hydrology and Drainage Design Manual* (1977) show that the increase in runoff on slopes of 10%, 15%, 20%, 25% and 30% is 12%, 20%, 25%, 28% and 30%, respectively, relative to slopes of 5% or less. Most of the vegetative soils in California have a runoff coefficient of 0.45 for conditions of the type that will prevail after site closure is complete. For Solano County, this coefficient is applicable to the mean (48 cm) and the 10-year annual (69 cm) rainfall event. For the 25-year (78 cm) and 100-year (90 cm) annual events, the coefficient increases to 0.5 and 0.56, respectively, on slopes of less than 10% and to 0.65 and 0.74 on slopes of 30%.

These coefficients indicate that the amount of water that would run off would be no less than 50% and as much as 74%, depending on the incline. The remaining water would either evaporate from the surface or infiltrate into the upper layer of the soil (vegetated soil cover). No measurable infiltration is expected to pass the vegetated cover layer on steeper slopes.

In the event that a small amount of rain does percolate through the vegetative cover and no drainage net exists, the chances that the water will proceed into the foundation layer are minuscule. This is because the clay layer must become saturated before water will pass through it. The optimal water content of clay at the time it is placed on top of the foundation layer is typically about 18%. At saturation, it typically has a water content of 27%. The void ratio and porosity of clay are 0.74 and 0.43, respectively. At a water content of 18%, the degree of saturation is 67%, leaving 14% of the volume available for water storage. Each unit volume of the 1 m thick layer of clay that would be installed as part of cover system B would be able to store an additional 13 cm of water. Calculations demonstrate that only 1.3 cm of water is expected to infiltrate into this layer every 10 years. Thus, even if the travel time of water through the clay is at the lower end of the previously mentioned range, it would still take 100 years for this layer to become saturated.

If cover systems that consist only of clays and a vegetative soil layer provide sufficient impermeable barriers to percolation, then it makes no sense to risk stability problems by including an FML in a closure cover when the slope of the cover exceeds 10%. Thanks to the low hydraulic conductivity of a clay layer and the unsaturated conditions that exist in it, the small amount of water that might pass into it will not travel to the foundation layer until the clay is saturated.

TYPICAL CLOSURE COVER



A TYPICAL RCRA CLOSURE COVER WITH AN FML (COVER SYSTEM A) AND WITHOUT (COVER SYSTEM B) IN SOLANO, A TYPICAL CALIFORNIA COUNTY.

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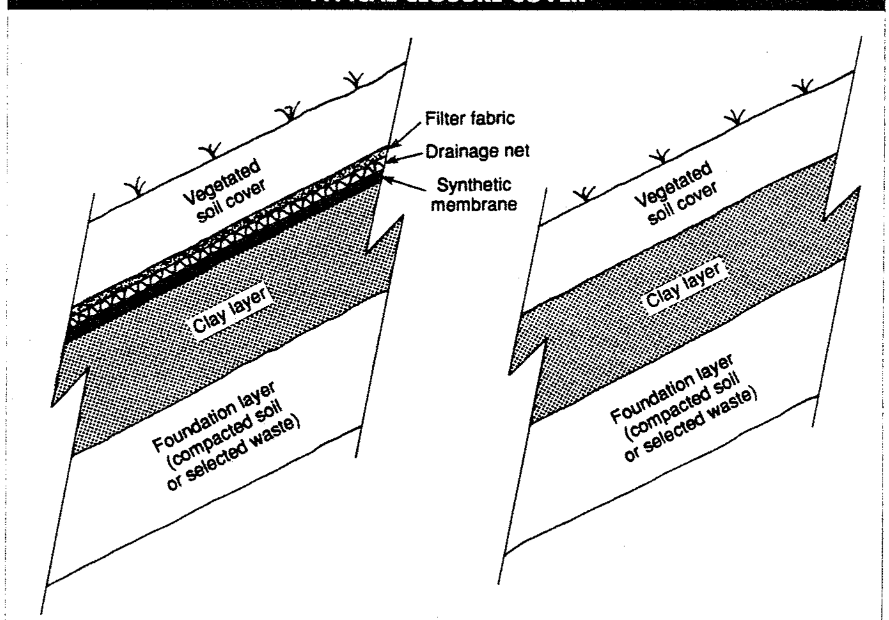

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